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Title: **INTELLIGENT HEARING AID**

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Title: INTELLIGENT HEARING AID

Field of the invention

[0001] The invention relates to hearing aids. More particularly, this invention relates to a hearing aid with associated means for automatically determining when the hearing aid should operate in a full-function mode or in a sleep mode.

Background of the invention

[0002] Hearing aid users commonly experience acoustic feedback when they insert a hearing aid into or remove a hearing aid from one of their ears since the hearing aid is usually turned on during the insertion or removal process. Further, the feedback that occurs during hearing aid insertion or removal can be annoying and can reduce the comfort level associated with wearing the hearing aid. Sometimes, the hearing aid user can insert the hearing aid into the ear without switching it on. However, if the hearing aid's power switch cannot be located while the aid is in the ear, the hearing aid user has to take the hearing aid out again, switch it on and then reinsert the hearing aid into the ear. This can upset the hearing aid user or at least cause inconvenience.

[0003] In addition, it is common for hearing aid users to forget to turn off their hearing aids after removing their hearing aids. This results in a reduction of the battery power of the hearing aid especially if the hearing aid user forgets to turn the hearing aid off at nighttime, in which case battery power is consumed overnight. Accordingly, it is desirable for the hearing aid to be automatically turned on when it is in use and automatically turned off otherwise.

[0004] Most hearing aids found in the market today, such as Behind-The-Ear (BTE) and In-The-Ear (ITE) hearing aids, have a power switch to allow the hearing aid user to manually turn the hearing aid on and off at any time. In the cases where the power switch is very small, it is very difficult for the hearing aid user to reach and operate the switch when the hearing aids are being worn. Other hearing aids, such as Completely-In-the-Canal (CIC) or

In-The-Canal (ITC) hearing aids, may have no power switch since these hearing aids are so small that it is difficult to install a power switch on the shell. In this case, the battery door may be used as the power switch to operate the hearing aids. Therefore, it is necessary to close the battery door first, while the hearing aid is in the hands of the hearing aid user, before inserting the hearing aid into the hearing aid user's ear. Unfortunately, when the hearing aid is turned on, while being held in the hearing aid user's hand, an open transmission path exists between the microphone and receiver of the hearing aid which will quickly lead to feedback and the production of a squealing sound.

[0005] In order to address the feedback problem when the hearing aid is switched on but not yet fully inserted into the ear, some newer digital hearing aids have a “Mute” or delayed start function, which can be programmed during the hearing aid fitting process. Such a feature will let the hearing aid user switch the hearing aid on first and then put the hearing aid into the ear during a preset “mute” or delay time while the output of the hearing aid is attenuated. Accordingly, no feedback will occur. However, the preset “mute” or delay time could be too short in some situations or too long in other situations. For instance, if the hearing aid user becomes otherwise occupied or distracted when the hearing aid user inserts the hearing aid, the hearing aid user may not have enough time to completely insert the hearing aid before the full-function mode is activated. In addition, if the hearing aid user is very old or has impaired movement due to a handicap, the hearing aid user might sometimes require a much longer time to completely insert the hearing aid. Alternatively, when the hearing aid user is in a hurry, he/she may quickly insert the hearing aid and expect it to work immediately. This may happen when the hearing aid user wakes up from sleep to answer a telephone and starts a conversation right away. In this case, a long “mute” or delay time will be not beneficial. In addition, it should be realized that even for the same hearing aid user, a preset “mute” or delay time may not meet all of the different requirements of daily life. Furthermore, the “mute” or delay feature is not useful when the hearing aid is removed from the ear since the

"mute" or delay feature does not prevent feedback in this situation before the hearing aid user can turn off the hearing aid.

[0006] Regardless of the aforementioned problems (i.e. feedback, comfort level and battery life) related to having to manually turn the hearing aid on and off, it is advantageous to eliminate the power switch from the hearing aid. Eliminating the power switch saves space, simplifies the mechanical design of the hearing aid and reduces the cost of manufacturing. The elimination of the power switch also increases the reliability of the hearing aid since the power switch is a moving mechanical part that is prone to failure over time.

Summary of the invention

[0007] The invention provides means for the implementation of an intelligent hearing aid that can determine whether to operate in a full-function mode or in a sleep mode which is an extremely low power consumption mode. The determination is based on whether the hearing aid is in the ear of the hearing aid user (i.e. the in-the-ear case) or out of the ear of the hearing aid user (i.e. the out-of-the-ear case). In the in-the-ear case, the hearing aid operates in full-function mode and in the out-of-the-ear case, the hearing aid operates in sleep mode. This feature of the invention prevents the hearing aid from experiencing feedback when a hearing aid user is inserting the hearing aid since the hearing aid is in sleep mode or when the hearing aid user is removing the hearing aid since the hearing aid will automatically move into sleep mode. Accordingly, the invention increases the comfort level associated with wearing the hearing aid, and allows the hearing aid user to put the hearing aid into the ear and remove the hearing aid from the ear as quickly or as slowly as the hearing aid user wishes without concern for feedback. This is particularly advantageous for older hearing aid users, who may have difficulty in quickly inserting the hearing aid into or quickly removing the hearing aid from their ear to avoid hearing a loud whistling noise due to feedback during the insertion or removal process.

[0008] The invention is also advantageous for hearing aid users who often forget to turn their hearing aids off when they remove the hearing aid since the hearing aid will automatically move to sleep mode. This may occur before they go to bed, for example. Accordingly, the invention saves battery life since the hearing aid operates in full-function mode only when it is in use and remains in sleep mode otherwise. The invention also provides a savings in battery life since acoustic feedback does not occur during hearing aid insertion or removal. In addition, the invention advantageously allows for testing the hearing aid in test equipment similar to that used for testing conventional hearing aids. In addition, the invention can be applied to various types of hearing aids such as CIC, ITC, ITE and BTE hearing aids.

[0009] In accordance with a first aspect, the invention provides a hearing aid for receiving an input signal and for providing a compensated output signal for a hearing aid user. The hearing aid is capable of automatically switching between a full-function mode and a sleep mode depending on the location of the hearing aid. The hearing aid comprises a hearing aid module for processing the input signal to generate the compensated output signal and, a location sensor module connected to the hearing aid module for providing a location information signal to indicate one of an in-the-ear case and an out-of-the-ear case. The hearing aid module automatically switches to the full-function mode when the location information signal indicates the in-the-ear case and the hearing aid module automatically switches to the sleep mode when the location information signal indicates the out-of-the-ear case.

[0010] In accordance with a second aspect, the invention provides a method for switching modes of operation in a hearing aid, wherein the hearing aid is capable of automatically switching between a full-function mode and a sleep mode depending on the location of the hearing aid. The method comprises:

a) providing a polling signal for determining the location of the hearing aid;

b) generating a location information signal after the polling signal is first provided, the location information signal indicating one of an in-the-ear case and an out-of-the-ear case; and,

c) automatically switching to the full-function mode if the location information signal indicates the in-the-ear case and automatically switching to the sleep mode if the location information signal indicates the out-of-the-ear case.

Brief description of the drawings

[0011] For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings which show an exemplary embodiment of the present invention and in which:

[0012] Figure 1 is a simplified block diagram of an exemplary embodiment of a hearing aid having a location sensor module for providing information about the location of the hearing aid in accordance with the invention;

[0013] Figure 2a is an exemplary schematic of the location sensor module of Figure 1;

[0014] Figure 2b is a timing diagram associated with the location sensor module of Figure 2a;

[0015] Figure 2c illustrates the light signal paths for the in-the-ear case for an exemplary embodiment of the emitter, detector and optical window;

[0016] Figure 2d illustrates the light signal paths for the out-of-the-ear case for an exemplary embodiment of the emitter, detector and optical window;

[0017] Figure 3a is another exemplary embodiment of the location sensor module of Figure 1;

[0018] Figure 3b is a timing diagram associated with the location sensor module of Figure 3a;

[0019] Figure 4 is a flowchart of a processing methodology for an intelligent hearing aid in accordance with the invention;

[0020] Figure 5a is an illustration of a BTE intelligent hearing aid showing the location of an optical window of the location sensor module in accordance with the invention;

[0021] Figure 5b is an illustration of the BTE intelligent hearing aid of Figure 5a in a normal sitting position in the out-of-the-ear case;

[0022] Figure 6a is an illustration of an ITE intelligent hearing aid showing the location of an optical window of the location sensor module in accordance with the invention;

[0023] Figure 6b is an illustration of the ITE intelligent hearing aid of Figure 6a in a normal sitting position in the out-of-the-ear case;

[0024] Figure 7a is an illustration of an ITC/CIC intelligent hearing aid showing the location of an optical window of the location sensor module in accordance with the invention; and,

[0025] Figure 7b is an illustration of the ITC/CIC intelligent hearing aid of Figure 7a in a normal sitting position in the out-of-the-ear case.

Detailed description of the invention

[0026] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the invention. Further, it should be understood that there are many variations of hearing aids because of variations in input channels, program switches, etc. Accordingly, exemplary embodiments of hearing aids in accordance with the invention are shown and described but are not meant to limit the invention.

[0027] A hearing aid in accordance with the invention is referred to as an intelligent hearing aid because the hearing aid has a location sensor module for determining the location of the hearing aid. Based on the location information, the hearing aid automatically operates in either a full-function mode or a sleep mode in which there is very low power consumption. The intelligent hearing aid operates in full-function mode when the location information indicates that the hearing aid is in the ear of the hearing aid user. Conversely, the intelligent hearing aid operates in sleep mode when the location information indicates that the hearing aid is not in the ear of the hearing aid user.

[0028] Referring first to Figure 1, shown therein is a simplified block diagram of an exemplary embodiment of an intelligent hearing aid **10** in accordance with the invention. The hearing aid **10** comprises an acoustic sensor **12**, an analog-to-digital converter (ADC) **14**, a system processor **16**, a location sensor module **18**, a digital-to-analog converter (DAC) **20** and a receiver **22** connected as shown in Figure 1. If the receiver **22** is a zero-bias receiver then the DAC **20** may be omitted. The system processor **16** includes a hearing aid module **24** and a power module **26** with voltage **V** and ground inputs **GND** connected to a battery **28**. The system processor **16** and its components may be implemented using a digital signal processor, and/or discrete electronic components, as is well known to those skilled in the art.

[0029] Alternative implementations of the hearing aid **10** can include other input means such as multiple microphones, an induction pick-up coil and a direct electrical input, or a bone conduction output as is well known to those skilled in the art. For simplicity, this description focuses on a single microphone input.

[0030] In use, when the hearing aid **10** is in full-function mode, the microphone **12** receives an acoustic input sound signal **30** and provides a corresponding analog input signal **32**. The acoustic input sound signal **30** contains desirable audio information and noise. The microphone **12** may be any type of sound transducer capable of receiving a sound signal and

providing a corresponding analog electrical signal. The ADC **14** receives the analog input signal **32** and produces a digital input signal **34**. The digital input signal **34** is then processed by the hearing aid module **24** to produce a digital output signal **36**. The output signal **36** can be considered to be a compensated output signal wherein the compensation is related to the hearing loss of the hearing aid user. Accordingly, the hearing aid module **24** may perform several functions on the digital input signal **34** such as amplification, adaptive noise filtering, compression, feedback cancellation, operating under various modes such as microphone mode or tele-coil mode and the like. These operations are well known to those skilled in the art. The digital output signal **36** is then converted to an analog output signal **38** by the DAC **20** and transduced by the receiver **22** to produce an output signal **40** that is presented to the user of the hearing aid **10**.

[0031] In general, the location sensor module **18** and the hearing aid module **24** communicate via a bi-directional information signal **42**. The hearing aid module **24** polls the location sensor module **18** via the bi-directional signal **42**, on preferably a periodic basis, to determine whether the hearing aid **10** is in the ear of the hearing aid user. In this case, the bi-directional signal **42** acts as a polling signal. In response to polling done via the bi-directional information signal **42**, the location sensor module **18** probes the outer environment of the hearing aid **10** and returns location information via the bi-directional location signal **42**. In this case, the bi-directional signal **42** acts as a location information signal. If the location information indicates that the hearing aid **10** is in the ear of the hearing aid user (i.e. the in-the-ear case), the hearing aid **10** operates in full-function mode. If the location information indicates that the hearing aid **10** is not in the ear of the hearing aid user (i.e. the out-of-the-ear case), the hearing aid **10** operates in sleep mode. In sleep mode, the hearing aid **10** can essentially be considered to be off.

[0032] There are several general scenarios for the location of the hearing aid. In the first scenario, the hearing aid **10** is not in the ear of the user and the hearing aid **10** and is in sleep mode. In this case, the location

sensor module **18** is polled and the location information indicates that the hearing aid **10** is not in the ear of the hearing aid user and the hearing aid **10** continues to operate in sleep mode. In the second scenario, the hearing aid **10** has just been inserted into the ear of the hearing aid user and the hearing aid **10** was previously in sleep mode. In this case, the location sensor module **18** is polled and the location information indicates that the hearing aid **10** is in the ear of the hearing aid user. The hearing aid **10** then moves into full-function mode. In the third scenario, the hearing aid **10** is in full-function mode and is being taken out of the ear of the hearing aid user. The location sensor module **18** is polled and the location information indicates that the hearing aid **10** is no longer in the ear of the hearing aid user. The hearing aid **10** then moves into sleep mode.

[0033] The invention generally relies on shining light having a particular wavelength on human skin as well as the reflectance properties of human skin. The surface reflection of the human skin occurs at the surface of the epidermis and is approximately independent of the lighting wavelength and independent of human race. In the infrared (IR) range the wavelengths that can be used are greater than 800 nano-meters and the surface reflectance of human skin is more or less constant and close to 50%. The same hold true for orange and red light in the visible light range, namely wavelengths between approximately 600 and 800 nano-meters can be used, although the surface reflectance for darker skin is reduced for shorter wavelengths. Surface reflectance for dark skin is approximately 25% at 700 nano-meters. In the embodiments shown herein, the energy of choice in the sensor unit **18** is preferably infrared (IR) energy. However, long wavelength visible light energy can also be used as discussed below.

[0034] Referring now to Figure 2a, shown therein is an exemplary schematic of the location sensor module **18**. In this case, the hearing aid module **24** has an output port **50** and an input port **52**. The location sensor module **18** has a transmission unit **54** that is connected to the output port **50**, an optical window **56** located on a portion of the shell **58** of the hearing aid **10**,

a blocking member **60**, and a reception unit **62** that is connected to the input port **52**. The transmission unit **54** emits IR energy preferably in the form of a series of pulses through the optical window **56**. If the hearing aid **10** is in the ear of the hearing aid user then the skin **64** of the hearing aid user will reflect the IR energy back through the optical window **56** to the reception unit **62**. The skin **64** may be the skin of the outer portion of the hearing aid user's pinna if the hearing aid **10** is a BTE hearing aid. Alternatively, the skin **64** may be the skin of the hearing aid user's concha or external auditory meatus if the hearing aid **10** is an ITE/ITC/CIC hearing aid.

[0035] The optical window **56** is placed at a certain location on the shell **58** of the hearing aid **10**. The location of the optical window **56** depends on whether the hearing aid is a BTE, ITE, ITC or CIC hearing aid. In addition, the location is chosen to minimize the distance between the optical window **56** and the skin **64.** For optimal reflection of IR signals back through the optical window, the hearing aid user's skin (i.e. the reflecting surface) is required to be immediately over the optical window **56**; otherwise the reflected IR energy will not be reflected back towards the reception unit **62**. The optical window **56** is typically a small window having a diameter of approximately 1 mm for example. The optical window **56** can be made from IR grade glass or other suitable material that allows for the passage of infrared energy (a different material would be used if visible light is used rather than infrared light). The optical window **56** should be kept clean at all times in order to prevent the emitted infrared energy from being reflected back due to dirt and the like that may accumulate on the optical window **56** over time. The location of the optical window **56** will be discussed in further detail below.

[0036] The blocking member **60** is mounted in the location sensor module **18** to ensure that the IR energy that is emitted by the transmission unit **54** is not directly transmitted to the reception unit **62**. Accordingly, the blocking member **60** is made from material that does not transmit IR energy.

[0037] The transmission unit **54** comprises at least a resistor **66** and a light emitter **68** that emits light in the visible light range or the IR light range. In

this exemplary embodiment, the emitter **68** is an IR emitting diode (i.e. an IR LED). One node of the resistor **66** is connected to the output port **50** and the other node of the resistor **66** is connected to the emitter **68**. The other node of the emitter **68** is connected to ground. The resistor **66** limits the current through the emitter **68**. In general, any current limiting network can be used in place of the resistor **66**. However, it is preferable to use a resistor for low-power consumption. The value of the resistor **66** depends on the internal resistance of the emitter **68** and the impedance of and voltage at the output port **50** of the hearing aid module **24**.

[0038] The transmission unit **54** receives a polling signal **70** from the output **50** of the hearing aid module **24**. The polling signal **70** is preferably a signal pulse that has a high logic level (i.e. a binary 1) when the hearing aid module **24** wants to determine whether the hearing aid **10** is in the ear of the hearing aid user. The resistance of the resistor **66** is such that polling signal **70'** has a sufficient amplitude to cause the emitter **68** to emit an IR emission signal **72**. The emitter **68** is positioned so that the IR emission signal **72** is directed through the optical window **56** at an oblique angle of incidence. After the IR emission signal **72** goes through the optical window **56**, the IR emission signal **72** is reflected back through the optical window towards the detector **74** if the optical window **56** is close to skin **64**, or another IR reflecting surface. Otherwise, the IR emission signal **72** is not reflected back towards the detector **74**. The latter condition indicates that the hearing aid **10** is not in the ear of the hearing aid user.

[0039] The reception unit **62** comprises at least a low power detector **74** and a resistor **76**. In this exemplary embodiment, the detector **74** is an IR optical transistor. Either a BJT or a FET optical transistor can be used, the preference being that the transistor consumes little power. Alternatively, the detector may be an IR photodiode. If the detector **74** is a BJT, then the resistor **76** is connected to the collector of the detector **74**, the emitter of the detector **74** is connected to ground and the base of the detector **74** is floating. If the detector **74** is a FET, the gate is floating, the drain is connected to the

resistor **76** and the source is connected to ground. Further, the detector **74** is positioned with respect to the optical window **56** to receive a reflected version of the IR emission signal **72**. The IR detector **74** may be positioned in a symmetrical fashion to the IR emitter **68**. The voltage **Vc** is provided by the power module **26** or another suitable component as is commonly known by those skilled in the art. The resistor **76** limits the current through the detector **74** when the received IR signal turns on the optical transistor. Also, the influence of naturally occurring steady state IR energy in the ear can be eliminated by biasing the detector **74** at a level such that the detector **74** only turns on when it detects IR energy that is higher than the amount of ambient IR energy.

[0040] The detector **74** provides a location information signal **78** to the input port **52** of the hearing aid module **24**. In this exemplary embodiment, the location information signal **78** is a constant signal which is typically at a high logic level (i.e. a binary 1) when no IR signal is being received by the detector **74**. However, when the IR emission signal **72** is reflected by the skin **64** to the reception unit **62**, the detector **74** receives a reflected IR signal **80**. This causes the detector **74** to produce a low logic level pulse (i.e. a binary 0) on the location information signal **78**. This provides an indication to the hearing aid module **24** that the hearing aid **10** is in the ear of the hearing aid user and that the hearing aid **10** should be operating in full-function mode. Otherwise, the location information signal **78** is constantly at a high logic level.

[0041] The hearing aid module **24** can process the location information signal **78** in a few different ways. The hearing aid module **24** can move into full-function mode after a time normally required to "start-up" processing once the location information signal **78** transitions to a low logic level from a high logic level during polling. Likewise, the hearing aid module **24** can move into sleep mode within an associated "shut-down" processing time when the location information signal **78** remains in a high logic level during polling.

[0042] Referring now to Figure 2b, shown therein is a timing diagram associated with the location sensor module **18**. The IR emission signal **72** is a

series of pulses **72a**, **72b** and **72c**. The low logic level states in the location information signal **78** that signify that the hearing aid **10** is in the ear of the hearing aid user are represented by pulses **78a**, **78b** and **78c**. Only three pulses and three low level logic states have been shown for simplicity. The IR emission signal **72** may comprise more or less than three pulses and there may be a comparable number of transitions in the location information signal **78** depending on whether the hearing aid module **10** is in the ear of the hearing aid user. A detection is defined when the low logic level state in the location information signal **78** reaches a specific level. There may also be other detection schemes which require more than one transition in the location information signal **78** in order to avoid false detection due to spurious signals.

[0043] As shown in Figure 2b, the IR emission signal **72** has a certain duration to allow the hearing aid module **24** to read the values provided in the location information signal **78**. Typically, the pulse duration of an IR emission signal **72** will be a short period, e.g. two clock cycles of the system processor **16**. In this case, the duration of a pulse in the IR emission signal **72** can be as short as 1 microsecond if the system clock is operating at 2 MHz. However, the period of the pulses in the IR emission signal **72** can be lower at higher clock frequencies. The low level logic state due to the reflected IR energy appears almost instantaneously at the input port **52**, and is sampled on the clock cycle (N+1) that occurs after the clock cycle (N) during which emission began. Accordingly, both the high logic level at the output port **50** and the low logic level at the input port **52** have a duration of approximately two clock cycles. Accordingly, the location sensor module **18** consumes minimal power in sleep mode since the module **18** will only work for about 0.001% of the time given a system clock speed of 2 MHz. Further, in sleep mode all analog circuits including the microphone **12**, ADC **14**, DAC **24** and the receiver **22** are turned off. Only a small portion of the digital circuitry of the hearing aid **10** functions and the circuitry that does function operates in an extremely low power mode to save battery power.

[0044] In both of the transition scenarios, i.e. from full-function mode to sleep mode, or from sleep mode to full-function mode, the hearing aid module **24** can perform more intelligent processing on the location information signal **78** to ensure that the location information signal **78** is providing reliable information and is not being influenced by environmental noise or other forms of interference. For example, body heat is not a problem since inadvertent triggering of the detector **74** due to ambient IR energy radiated from the human body can be prevented by correctly biasing the detector **74**, thereby rendering the detector **74** immune to a background IR energy level. In addition, the influence of transient high level IR signals can be eliminated by requiring a high logic state at the output port **50** and the input port **52** to be present simultaneously. Further, temperature change in body heat is not problematic since the temperature in the ear (or behind the ear) changes over a relatively small range.

[0045] Referring now to Figures 2c and 2d, shown therein is a more detailed embodiment of the spatial relationship between the emitter **68**, the optical window **56**, the detector **74**, and the skin **64** of the hearing aid user or another light reflecting surface. The emitter **68** is positioned so that the signal **72** from the emitter **68** is beamed down an enclosed channel **69** towards the optical window **56**. For the in-the-ear case shown in Figure 2c, the skin **64** is immediately next to the optical window **56** and reflects the emitted signal **72** back into a second channel **73** towards the detector **74**. Figure 2d shows the out-of-the-ear case in which the skin **64** is at some distance removed from the optical window **56**. In this case, the reflected beam **80'** misses the optical window **56**. The detector **74** does not receive the reflected signal **80'** and remains in a high logic level state thereby signaling the out-of-the-ear case. Figures 2c and 2d also show that the emitter **68** and the detector **74** are placed at complementary angles with respect to one another, i.e., the angle that the longitudinal axis of the emitter **68** makes with respect to the blocking member **60** is substantially similar to the angle that the longitudinal axis of the detector **74** makes with respect to the block member **60** since the angle of incidence of the emission signal **72** is the same as the angle of reflection of

the reflected signal **80**. The blocking member **60** can consist of a discrete light barrier shown in Figure 2c and Figure 2d. Alternatively, the material making up the walls of channels **69** and **73** or the material between channels **69** and **73** can constitute the blocking member 60 if these materials do not transmit visible or IR light.

[0046] Referring now to Figure 3a, shown therein is another exemplary embodiment of a location sensor module **18'**. Similar reference numerals are used to represent elements that are similar to those of the location sensor module **18**. This embodiment preferably uses IR signals to distinguish between the in-the-ear case and the out-of-the-ear case. However, certain wavelengths of visible light may also be used as previously described. In some system processors, the available I/O ports may be limited. Accordingly, there may be only one I/O port available for the location sensor module **18'**. In this case, the hearing aid module **24** only uses one I/O port **82** and communicates via bidirectional signal **42** for both sending the polling signal **70** to the transmission unit **54** and receiving the location information signal **78** from the reception unit **62'**. To facilitate this bi-directional communication scheme, the reception unit **62'** includes a delay unit **84** and a transmission gate **86**. One node of the time delay unit **84** is connected to the collector or drain of the detector **74** (depending on whether a BJT or a FET is used) and the other node of the delay unit **84** is connected to one of the nodes of the transmission gate **86**. The other end of the transmission gate **86** is connected to the I/O port **82**. In alternative embodiments, the delay unit **84** may be placed in the transmission unit **54** or may be placed in both the transmission unit **54** and the reception unit **62**.

[0047] In use, the hearing aid module **24** first configures the I/O port **82** as an output port and sends the polling signal **70** to drive the emitter **68** to emit the IR emission signal **72**. After an appropriate delay, the hearing aid module **24** will configure the I/O port **82** to be an input port to receive the location information signal **78**. The delay provided by the delay unit **84** is preferably on the order of 1 to 2 system clock cycles (i.e. approximately 0.5 to

1 microseconds if the system clock runs at 2 MHz) to allow the hearing aid module **24** to reconfigure the I/O port **82** as an input port. A typical delay that may be used is 1.5 cycles.

[0048] The transmission gate **86** blocks the location information signal **78** from the I/O port **82** and the transmission unit **54** when the I/O port **82** is configured to operate as an output port. Alternatively, when the I/O port **82** is configured to operate as an input port, the transmission gate **86** transmits the location information signal **78'** to the I/O port **82**. In this exemplary embodiment, the transmission gate **86** is a diode. Accordingly, prior to the emission of an IR pulse by the emitter **68**, the polling signal **70** has a low logic value, there is no IR energy emitted and the location information signal **78** has a high logic value, In this case, the diode **86** is reverse biased, will not conduct current and will isolate the transmission unit **54** from the high logic value of the location information signal **78**. However, during the transmission of an IR pulse, the polling signal **70** has a high logic value and IR energy is transmitted by the emitter **68**. For the in-the-ear case, the IR energy reflects, the detector **74** receives the reflected IR signal **80** and the location information signal **78** transitions to the low logic level. In this case, the diode **86** is forward biased, after an appropriate delay, and will conduct current thereby allowing the I/O port **82** to sense the transition to a low logic level on the location information signal **78'**. After the hearing aid module **24** reads the I/O port **82**, the hearing aid module **24** will reconfigure the I/O port **82** to be an output port and will provide a low logic value for the polling signal **70**.

[0049] Referring now to Figure 3b, shown therein is a timing diagram associated with the location sensor module **18'**. The first line of the timing diagram shows the IR emission signal **72** that is emitted by the transmitter **68** at clock cycle N. This case shows an example in which the duration of the IR emission signal **72** is only 1 clock cycle. For the embodiment of the location sensor module **18'**, the response encoded in the information signal **78** occurs almost instantaneously and lasts for the same clock cycle duration. However, for the embodiment of the location sensor module **18'**, the response **78** is

delayed by a time td such that the response is encoded in the information signal **78'** during the N+1 and N+2 clock cycles. The response is actually detected by the hearing aid module **24** at clock cycle N+2 (as represented by the arrow).

[0050] Referring now to Figure 4, shown therein is a flowchart of a processing methodology **90** for an intelligent hearing aid in accordance with the invention. The processing methodology **90** starts at step **92** in which the battery **28** is first inserted. The hearing aid module **24** then initializes the hearing aid **10** in step **94** and the hearing aid **10** enters sleep mode. Sleep mode involves turning all unneeded circuitry and hearing aid processing off. In sleep mode, the hearing aid module **24** also sets an enable timer or a watchdog circuit to create an interrupt at a predetermined time. The majority of the hearing aid **10** operates in sleep mode during the interrupt process. If a time constant **TN** of 0.1 seconds is used, for example, to create the interrupt, then the portion of the hearing aid module **24** associated with polling will "wake-up" to send a high logic level on the polling signal **70** in step **96** and read the location information signal **78** in step **98**. The total duration of steps **96** and **98** will be very short, approximately 2 clock cycles, for example. In step **100**, the hearing aid module **24** determines whether the hearing aid **10** is in the ear of the hearing aid user. If the determination is negative, the process **90** will go back to step **96** and wait for the next interrupt to occur. Accordingly, as long as the hearing aid **10** is not in the ear of the hearing aid user, the hearing aid **10** will consume very little battery power and no feedback will occur.

[0051] If the hearing aid module **24** determines that the hearing aid is in the ear of the hearing aid user in step **100**, then the process **90** moves to step **102** in which the hearing aid **10** moves into full-functional mode and the circuitry of the hearing aid **10** is fully enabled after a time delay normally associated with the startup time of the system processor to reach normal hearing aid operation. This ensures that the hearing aid **10** is fully positioned in the ear. At this point, a time counter **TC** is set to 0. The time counter **TC** is

implemented via a dedicated service routine or an internal time counter. The next step **104** is for the hearing aid to function as it normally would. During full-function mode, the time counter **TC** is updated in step **106** and the hearing aid module **24** checks to see whether the counter **TC** has reached the time constant **TN** in step **108**. If not, the hearing aid **10** continues to operate in full-function mode. However, once the time counter **TC** reaches the time constant **TN**, the hearing aid module **24** sends the polling signal **70** in step **110** and reads the location information signal **78** in step **112**. Alternatively, a preprogrammed timer interrupt can be used instead of time constant **TN**.

[0052] If it is determined in step **114** that the hearing aid **10** is still in the ear of the hearing aid user, then the process moves to step **104** and the hearing aid module **24** resets the counter **TC** and waits for the next time interrupt to occur. However, it if is determined in step **114** that the hearing aid **10** is no longer in the ear of the hearing aid user, the process moves to step **94** in which the hearing aid module **24** turns off all analog circuits and hearing aid processing, sets the timer interrupt or watchdog circuit with a wait time **TN** and the hearing aid **10** enters sleep mode.

[0053] The hearing aid **10** can poll the location sensor module **18** on a periodic basis as is described above. However, the interrupt frequency can be varied under different circumstances. For instance, if the hearing aid **10** is in full-function mode, it can be likely that the hearing aid **10** will continue to operate in full-function mode for a while. In this case, the interrupt frequency can be decreased. An "InEar" timer can keep track of the amount of time that the hearing aid **10** is in the ear of the hearing aid user. Once the InEar timer indicates that the hearing aid **10** has been in the ear for a certain time duration, such as 14 hours for example, it can be expected that the hearing aid user will soon be removing the hearing aid **10**. In this case, the interrupt frequency can be increased.

[0054] Conversely, when the hearing aid **10** is in sleep mode, it can be likely that the hearing aid **10** will continue to operate in sleep mode for a while. In this case, the interrupt frequency can be decreased. Similarly to the in-the-

ear case, an "OutofEar" timer can keep track of the amount of time that the hearing aid **10** is out of the ear of the hearing aid user. Once the OutofEar timer indicates that the hearing aid **10** has been out of the ear for a certain time duration, such as 6 hours for example, it can be expected that the hearing aid user will soon be inserting the hearing aid **10**. In this case, the interrupt frequency can be increased.

[0055] Referring now to Figure 5a, shown therein is an illustration of a BTE intelligent hearing aid **120** showing the location of the optical window **56** in accordance with the invention. In general the optical window **56** can be placed along the inner surface **122** of the BTE hearing aid **120**. However, it is preferable to place the optical window **56** on the upper inner surface **122u** of the BTE hearing aid **120** where the BTE hearing aid **120** fits snugly against the outside of the hearing aid user's ear when the BTE hearing aid **120** is worn. The optical window **56** is preferably located such that it is as close as possible to the skin of the hearing aid user during the in-the-ear condition. Of course, it should be understood that the BTE intelligent hearing aid **120** is not placed inside the ear and so the in-the-ear case simply means that the BTE intelligent hearing aid **120** is being worn by the hearing aid user.

[0056] Figure 5b shows the BTE intelligent hearing aid **120** in a normal sitting position for the out-of-the-ear case. The inner surface **122** where the optical window **56** is located is facing horizontally almost parallel with the surface upon which the hearing aid **120** is sitting. Accordingly, the optical window **56** is "open", there is no reflection of IR energy back to the optical window **56** and the hearing aid **120** is in sleep mode.

[0057] Referring now to Figure 6a, shown therein is an illustration of an ITE intelligent hearing aid **130** showing the location of the optical window **56** in accordance with the invention. In general the optical window **56** can be placed on the surface of a region **132** which matches the shape (i.e. concave or convex) of the concha or external auditory meatus in a complementary fashion to provide a snug, comfortable fit for the hearing aid user. This

location ensures that the optical window **56** is against the skin of the hearing aid user when the hearing aid **130** is being worn.

[0058] Figure 6b shows the ITE intelligent hearing aid **130** of Figure 6a in a normal sitting position for the out-of-the-ear case. The region **132** where the optical window **56** is located is facing downwards and there is a large gap **134** between the optical window **56** and the surface upon which the hearing aid **130** is sitting. Accordingly, the optical window **56** is "open", there is no reflection of IR energy back to the optical window **56** and the hearing aid **130** is in sleep mode. In this case, since the reflecting surface is not located immediately next to the optical window **56**, the reflected IR energy will miss the optical window **56** and therefore not reach the detector **74**. The basic cylindrical window shape can be further refined to ensure that only reflecting surfaces immediately on top of the optical window **56** will trigger a response from the detector **74**. For example a truncated cone shape with the smaller diameter facing out can be used.

[0059] Referring now to Figure 7a, shown therein is an illustration of an ITC/CIC intelligent hearing aid **140** showing the location of the optical window **56** in accordance with the invention. Once again, the optical window **56** is located on the surface of a region **142** of the hearing aid **140** that matches the shape of the concha or external auditory meatus in a complementary fashion to provide a snug, comfortable fit for the hearing aid user. This location ensures that the optical window **56** is against the skin of the hearing aid user when the hearing aid **140** is being worn.

[0060] Figure 7b shows the ITC/CIC intelligent hearing aid **140** of Figure 7a in a normal sitting position for the out-of-the-ear case. The region **142** where the optical window **56** is located is facing downwards at an angle and there is a large gap **144** between the optical window **56** and the surface upon which the hearing aid **140** is sitting. Accordingly, the optical window **56** is "open", there is no reflection of IR energy back to the optical window **56** and the hearing aid **140** is in sleep mode.

[0061] For each of the BTE hearing aid **120**, ITE hearing aid **130** and the ITC/CIC hearing aid **140**, the optical window **56** is "open" when each of the hearing aids **120**, **130** and **140** is not in the ear, such as when each of the hearing aids **120**, **130** and **140** is put on a table, in the hand or in a drawer. In these cases, the hearing aids **120**, **130** and **140** will be in sleep mode. Furthermore, when the hearing aids **120**, **130** and **140** are put into a storage container for storage while not in use, the hearing aids **120**, **130** and **140** are unlikely to switch into full-function mode since the optical window **56** will not be directly against an inner surface of the storage container. Conversely, the optical window **56** is "blocked" when the hearing aids **120**, **130** and **140** are worn by the hearing aid user since the optical window **56** will be against the hearing aid user's skin. In this case, the hearing aids **120**, **130** and **140** will be in full-function mode.

[0062] While the intelligent hearing aids of the invention are in full-function mode only when the hearing aid is being worn by the hearing aid user, it is still possible to conduct product tests and performance verification on the intelligent hearing aids as is conventionally done with all hearing aids. These tests may involve putting the intelligent hearing aids in a test box. During testing, a piece of tape, a sticker, or any other material that reflects IR energy can be used to cover the optical window **56**. In this case, the intelligent hearing aid will be operating in full-function mode.

[0063] In an alternative embodiment, as previously mentioned, visible light and a plain glass window may be used rather than IR light. In this case, the emitter and the detector are photo-electronic elements that can generate and detect light, respectively, in the visible light spectrum. Further, the blocking member is made of a material that blocks the passage of visible light. The remainder of the structure of the location sensor module is as described for location sensor module **18** or location sensor module **18'**. However, in this embodiment, the hearing aid module behaves slightly differently. For instance, the hearing aid module can simply poll the detector for the presence of visible light without having the emitter emit visible light. If visible light is detected,

then the hearing aid is out of the ear and the hearing aid is put into sleep mode. If visible light is not detected, then the hearing aid is either in the ear or out of the ear but in a dark room or in a box. The hearing aid then goes into a polling mode in which the emitter emits visible light at a certain period such as 0.1s. If the detector detects visible light after the emitter emits visible light (similar to the IR case), the hearing aid is in the ear and the hearing aid operates in full-function mode. If the detector does not detect visible light in this case, the hearing aid is out of the ear and the hearing aid operates in sleep mode. In this alternative embodiment, ambient light is ignored by setting an appropriate threshold in the detector.

[0064] It should be understood by those skilled in the art that, for each embodiment of the hearing aid shown herein, the detector applies a first level of detection criteria to the received light signal to determine if the light signal is ambient infrared light or a truly reflected IR light signal or a visible light signal. In all cases, the hearing aid module may apply a second set of detection criteria, such as requiring two or more consecutive transitions on the location information signal so that transient or spurious light signals do not cause a false detection.

[0065] It should be understood that various modifications can be made to the embodiments described and illustrated herein, without departing from the present invention, the scope of which is defined in the appended claims.